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13. ABSTRACT *(Maximum 200 words)*
Anecdotal evidence suggested that signals recorded using computerized polygraph instruments with the galvanic skin response (GSR) channel set in the manual mode are substantially different from those recorded with the instrument set in the automatic mode. This had been difficult to confirm since equipment was not available that would generate continuously variable resistance signals of known shape, magnitude, and frequency. Such a device was conceptualized, designed, constructed, tested, and aligned in the laboratory using readily available electronic components. The response characteristics of various computerized polygraph instruments were subsequently analyzed using the device. Results confirmed the verbal reports of differences between signal characteristics in the manual and automatic modes.

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Instrumentation for Presenting a Known Standard Signal to the GSR Channel for Assessing Response Characteristic of Selected Polygraph Instruments

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May 1997

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Director's Foreword

Over the past 50 years a variety of polygraph instruments have been manufactured and sold specifically for use during the detection of deception. Manufacturers were trusted to provide reliable instruments that accurately reproduced human physiological reactivity. Little, if anything, was done to measure or specify the signal processing characteristics of commercial polygraph instruments.

With the advent of computerized polygraphs, there has been increasing concern that the signal processing and reproduction abilities of instruments could differ. It has been suggested that there are dissimilarities in response tracings observed among the various instruments. There is further concern regarding the differences between signals processed using the manual and automatic mode options offered by some computerized instruments.

There has, to date, been little effort to quantify, or even systematically describe, the differences among polygraph instruments. This manuscript describes the first in a series of steps intended to develop standards for polygraph instrument evaluation and manufacture. Further studies will be conducted to quantify the instrument filter and amplifier response characteristics, and to determine if these characteristics have an effect on the interpretation of physiological responding.

Michael H. Capps
Director

This project was funded by the Department of Defense Polygraph Institute as DoDPI96-P-0013. The views expressed in this article are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

Abstract

Cestaro, V. L. Instrumentation for presenting a known standard signal to the GSR channel for assessing response characteristics of selected polygraph instruments. May 1997, Report No. DoDPI96-R-0004. Department of Defense Polygraph Institute, Ft. McClellan, AL 36205.—Anecdotal evidence suggested that signals recorded using computerized polygraph instruments with the galvanic skin response (GSR) channel set in the manual mode are substantially different from those recorded with the instrument set in the automatic mode. This had been difficult to confirm since equipment was not available that would generate continuously variable resistance signals of known shape, magnitude, and frequency. Such a device was conceptualized, designed, constructed, tested, and aligned in the laboratory using readily available electronic components. The response characteristics of various computerized polygraph instruments were subsequently analyzed using the device. Results confirmed the verbal reports of differences between signal characteristics in the manual and automatic modes.

Key words: computerized polygraph, GSR, linearity, response, standardized signal, simulation, skin resistance, PDD

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Forensic psychophysiologists in the field claimed that the galvanic skin response (GSR) channel on computerized polygraph instruments displayed markedly different responses, depending on whether the signals were recorded in the manual or automatic mode. There was no way to easily verify which signal was the more accurate representation of the physiological changes monitored by the instrument. Most modifications made to the later instruments appeared to be directed at making the equipment easier to use and the output easier to interpret within the context of the psychophysiological detection of deception (PDD).

It was decided that the most rational approach to addressing the linearity issue was to test all instruments, using input signals of known shape, amplitude, and frequency, and then to compare the outputs to the output of an amplifier devoid of any filtering or shaping circuits.

Instrument Design

Concept

The GSR test fixture, hereinafter referred to as the simulator, should be capable of presenting a constantly changing resistance to the input of the polygraph GSR channel. The baseline resistance should be adjustable to simulate a portion of the range of human tonic skin resistance, and dynamically change at a rate equivalent to that of the human phasic response observed during PDD examinations, with an adjustment for center frequency of the phasic response. The signal should also have a known output waveshape in order to provide a subjective assessment of the linearity of the target instruments. It was decided that the device should be capable of presenting sine, triangle, and square waves, with frequencies adjustable from 0.1 to 1 Hz, with an adjustable tonic resistance level of 10K ohms (10,000 ohms) to 100K ohms, and a selectable dynamic (corresponding to phasic) response of 5K and 10K ohms. Additionally, provision would be made to accommodate an external input signal to drive the device. The simplest way to control resistance to the input of the GSR channel would be to use a light sensitive resistor (photoresistor) and a controllable light source. However, it was found that simply varying the magnitude of the voltage to a lamp filament, or to a light emitting diode (LED), resulted in a voltage to resistance transfer function that was too nonlinear to be useful. The most linear function, using an LED/photoresistor pair, was obtained during lab tests using a combination of pulse-width and frequency modulation of the LED.

Design

The simulator was designed using a combination of linear and digital integrated circuits (refer to Figure 1). The primary output waveforms are obtained from the 8038 function generator (U1). The 8038 has three simultaneous outputs; sine, square, and triangle waveforms. Only the square wave output is nonlinear, having a voltage swing from ground to Vdd (the input power supply voltage level). The other two outputs are linear with maximum amplitudes approximately equal to Vdd/4 for the sine wave and Vdd/3 for the triangle. The frequency of all three waveforms is simultaneously controlled by R1, which is adjustable from 0.1 to 1.0 Hz. Waveform symmetry is controlled by R2, and is adjusted for best sine or triangle symmetry at 0.5 Hz. Potentiometers R4 and R5 are used to adjust the sine output for

minimum distortion (third harmonic and peaks). All three outputs are alternating current (AC) coupled to a 4066 analog switch (U2) through level adjustment potentiometers (R6, R7, and R8). Selection of signals switched through the 4066 is accomplished by a 4017 decade counter (U7) used as a stepping switch, clocked manually by an LM555 timer (U5) wired as a monostable multivibrator (one-shot) triggered by a front-panel momentary push-button switch (S2) connected to a differentiating network in front of the one-shot.

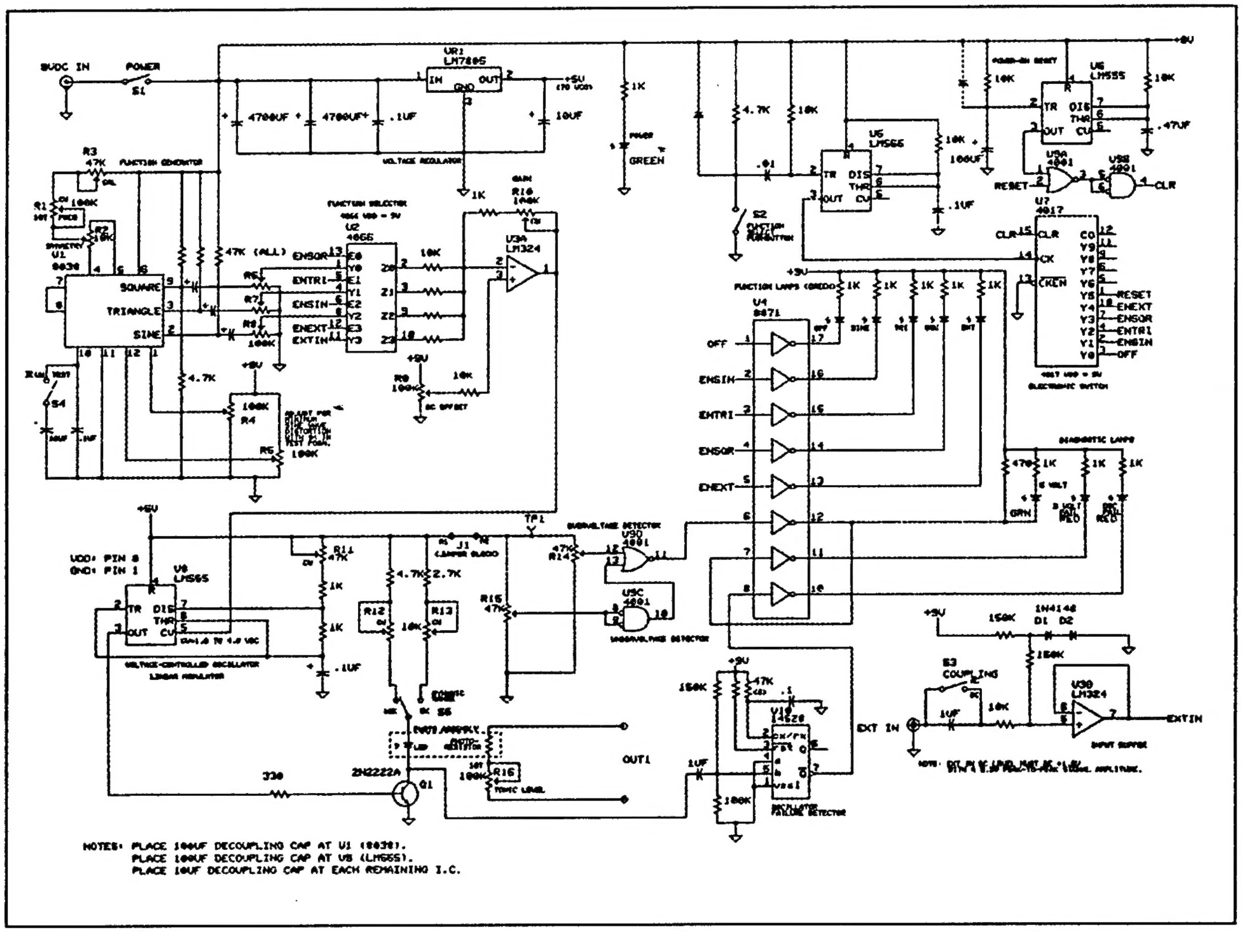

Figure 1. Schematic diagram of the GSR test device (simulator).

The four outputs of the 4066 are fed through 10K ohm resistors to a summing junction at the input of an LM324 operational amplifier (U3A), with adjustable gain and output offset, which in turn is direct current (DC) coupled to the control input of U8, an LM555 configured as a voltage controlled oscillator (VCO). The offset control (R9) is used to set the starting frequency of the VCO by adjusting the trough of the triangle wave to 1.0 volts (DC level). The range of the VCO control voltage is set for 1.0 to 4.0 volts, with the 4.0 volt upper limit (triangle wave peak) determined by the gain setting of the LM324 amplifier (U3A). The three waveforms are adjusted for equal amplitudes at the output of U3A by R6, R7, and R8. The linearity of the voltage to frequency transfer of the VCO was found to be satisfactory for this application. The VCO output is connected to the base of a 2N2222A NPN transistor which functions as a pulse modulated current sink for the LED wired to the collector of the

transistor. Source current to the LED is determined by the range switch (S5), which can select one of two current ranges (through R12 and R13) and hence, the resistance change seen at the photoresistor. The voltage for U8 and the modulator transistor is held constant by an LM7805 voltage regulator (VR1). The response time of the photoresistor is long enough to cause it to act as a low-pass/high-reject filter to smooth out the 25-50 Khz (25,000 to 50,000 Hz) light pulses from the LED. The change in resistance, which follows the low frequency control voltage waveform at pin 5 of U8, is ripple-free. Potentiometer R16 is used to adjust the baseline resistance level (tonic GSR).

An additional LM555 (U6) is wired as a one-shot to apply a reset pulse to U7 so that when power is applied the device starts in the OFF state (no signal to the VCO). A 14528 retriggerable one-shot (U10) is used to detect the presence of pulses at Q1 collector and lights a diagnostic lamp to enunciate the loss of pulse modulation to the LED. U9C and U9D are used to detect loss of regulation of the +5 volt supply to the VCO, and will illuminate a red front panel lamp if the voltage falls to less than 4.7V or rises above 5.3V. Within the normal voltage range, a green lamp is illuminated. An 8871 open-collector driver (U4) is used to illuminate the various front panel function and diagnostic LEDs. An external function generator or other modulating device may be used to drive the system through the external input at U3B. Two 1N4148 diodes in series (D1 and D2) are used to clamp the input at approximately one volt so that the baseline of the external signal is roughly equivalent to the three internal signal baselines in order to avoid large excursions on the display of the unit under test when the signal source is switched.

The simulator was assembled on a general-purpose component PC board purchased from Radio Shack (#276-147A), and installed in a plastic enclosure also purchased from Radio Shack. The general component layout is shown in Figure 2. Initial alignment of the simulator was accomplished using an oscilloscope to monitor the output of the 8038 with switch S4 in the test position (higher frequency). The final alignment in the 0.1 to 1 Hz operating frequency range was done using a data acquisition board and software installed in an IBM compatible 486 personal computer. In order to convert the resistance output of the simulator to voltage for the data acquisition system, a resistance to voltage converter was built (Figure 3).

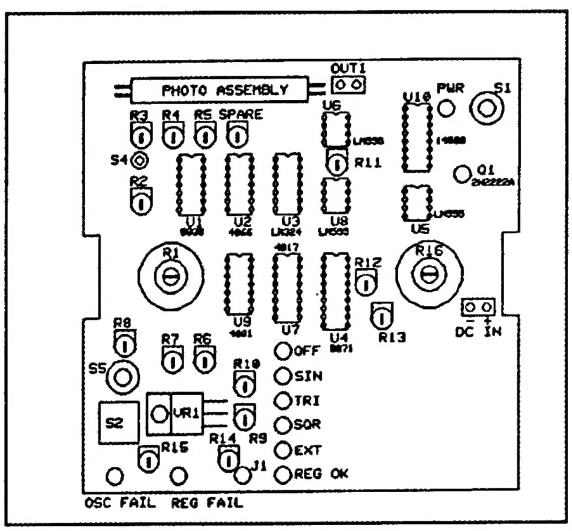

Figure 2. Component layout of GSR simulator.

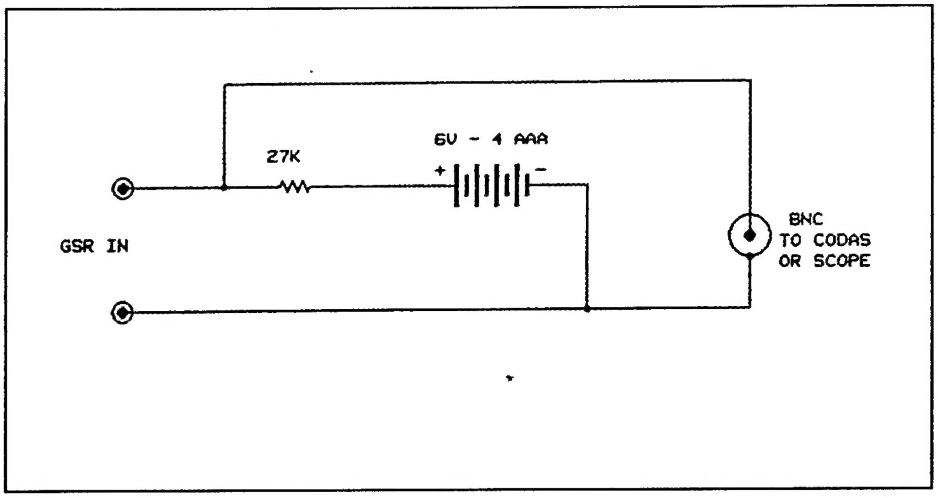

Figure 3. Resistance to voltage converter for the CODAS system.

Method

Apparatus

A four-channel oscilloscope (Model 2247A, Tektronix, Beaverton, OR) was used to test and align the simulator prior to testing the polygraph instruments, and for monitoring the simulator output during testing. An IBM compatible 486 computer with an internal Dataq analog to digital converter (adc), using CODAS data acquisition and display software (Dataq Instruments Inc., Akron, OH) was used to record the output of the simulator to establish a measurement standard. Three computerized polygraph instruments were tested for response linearity: (a) Lafayette LX2000, (b) Stoelting CPS (software version 2.14D), and (c) Axciton (Interface Box Version S7.1, software release 4.9). Input to the CODAS adc was not filtered. A flatbed scanner (Model IIcx, Hewlett-Packard, Palo Alto, CA), attached to an IBM compatible 486 computer, was used to scan polygraph charts and save them on magnetic media as computer image files.

Procedure

The GSR channel leads on each instrument were individually connected to the GSR output of the simulator. The simulator frequency control was adjusted for an output frequency of 0.1 Hz. The simulator tonic GSR level control was adjusted to 50K ohms. The simulator range switch was set to 5K or 10K, depending on the instrument being tested, to get a GSR trace that would remain within the limits of the GSR channel amplifier linear region. Three one minute data epochs were collected for sine, square, and triangle wave outputs from the simulator for each instrument. Data were subsequently printed on paper charts for each of the three instruments. Finally, the paper charts were scanned into tagged image format (TIF) computer files for post analysis using the Hewlett-Packard scanner.

Results

The output of the GSR channels on the Axciton and the Lafayette instruments differed between the AUTO and MANUAL modes of operation. The Stoelting system was not switchable. Figures 4, 6, and 8 show the output of the Axciton instrument in the AUTO mode. Figures 5, 7, and 9 depict the same instrument in the MANUAL mode. The positive baseline shift apparent in Figures 5, 7, and 9 was not seen on the input signal, but is related to some function within the Axciton polygraph instrument. This baseline shift was not observed on the other two instruments, nor on the CODAS system used to calibrate the simulator. Additionally, nonlinear transduction of the triangle and square wave resistance signals was observed on the Lafayette LX2000 and the Axciton systems in the AUTO mode (Figures 6, 8, 12, and 14). Signal linearity was good for the sine wave on the Stoelting CPS, with some distortion on the triangle and square waves (Figure 16). Linearity was good for the sine wave in the AUTO and MANUAL modes on the LX2000 and the Axciton (Figures 4, 5, 10 and 11). Some distortion was observed on the triangle and square waves in the MANUAL mode on the Axciton and Lafayette (Figures 7, 9, 13, and 15). In all cases, the instrument sensitivity (gain) was not adjusted when changing from AUTO to MANUAL. Amplitude differences observable in the figures are due to internal differences between the two modes of operation.

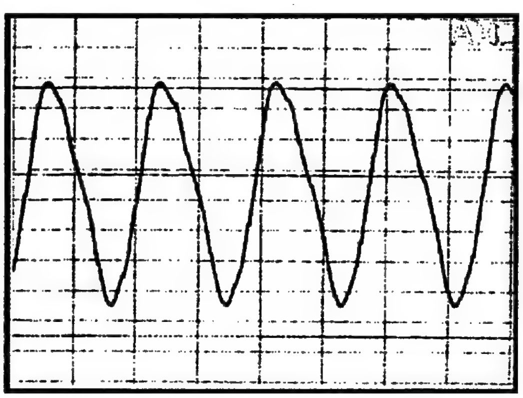

Figure 4. Axciton chart showing a 0.1 Hz sine wave on the GSR channel in AUTO

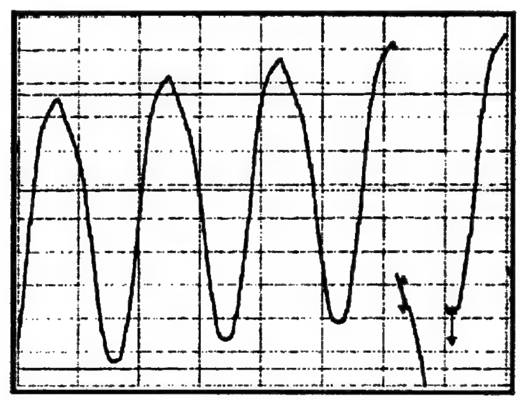

Figure 5. Axciton chart showing a 0.1 Hz sine wave on the GSR channel in MANUAL

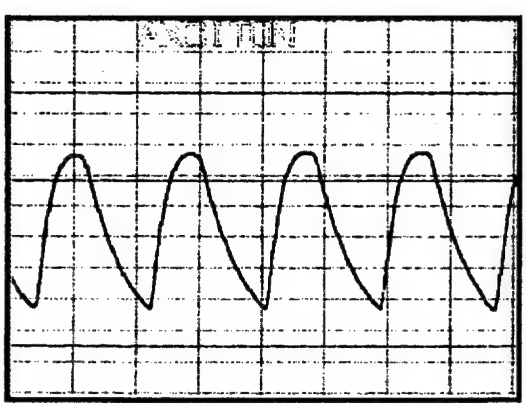

Figure 6. Axciton chart showing a 0.1 Hz triangle wave on the GSR channel in AUTO mode.

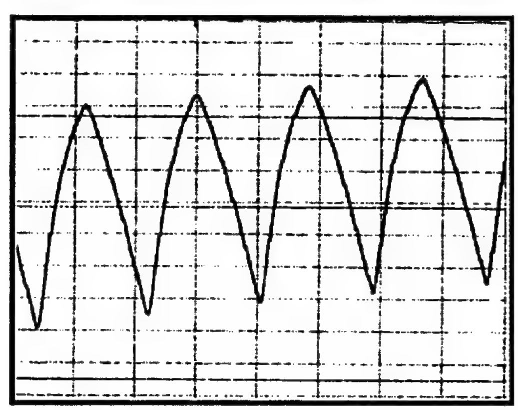

Figure 7. Axciton chart showing a 0.1 Hz triangle wave on the GSR channel in MANUAL mode.

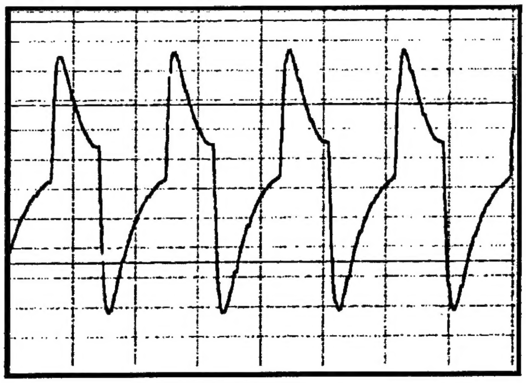

Figure 8. Axciton chart showing a 0.1 Hz square wave on the GSR channel in AUTO mode.

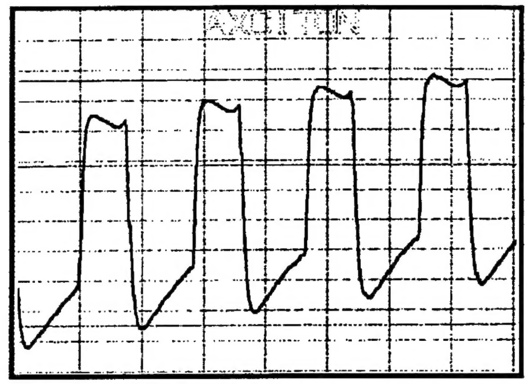

Figure 9. Axciton chart showing a 0.1 Hz square wave on the GSR channel in MANUAL mode.

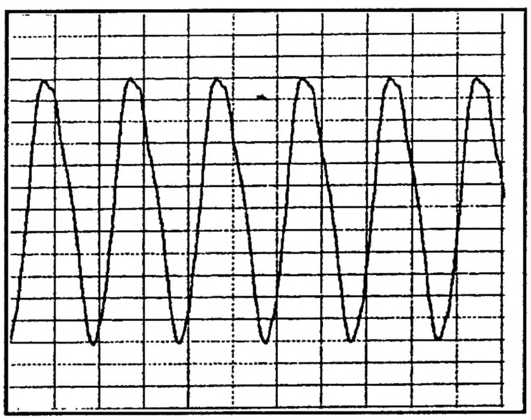

Figure 10. LX2000 chart showing a 0.1 Hz sine wave on the GSR channel in AUTO mode.

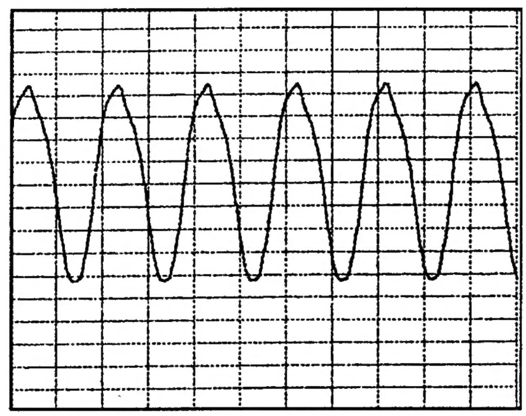

Figure 11. LX2000 chart showing a 0.1 Hz sine wave on the GSR channel in MANUAL mode.

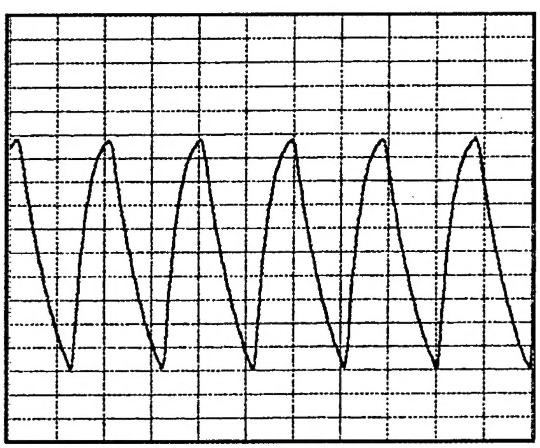

Figure 12. LX2000 chart showing a 0.1 Hz triangle wave on the GSR channel in AUTO mode.

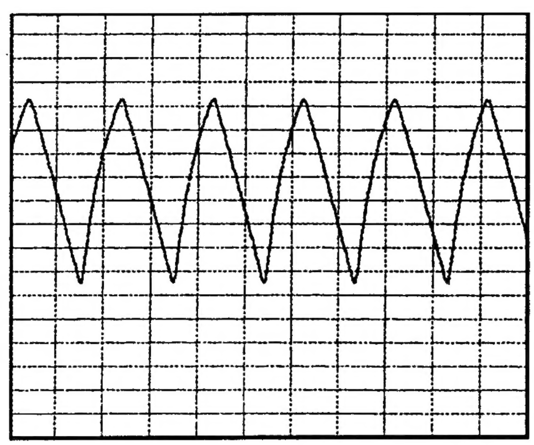

Figure 13. LX2000 chart showing a 0.1 Hz triangle wave on the GSR channel in MANUAL mode.

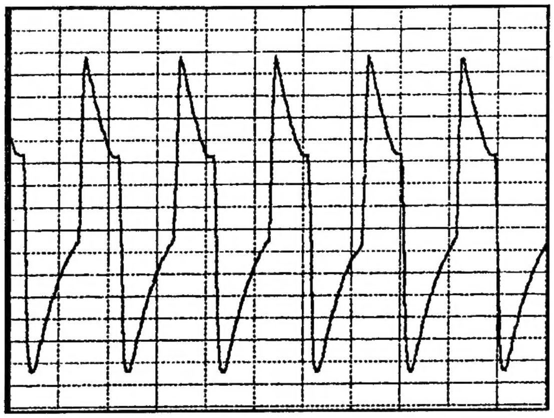

Figure 14. LX2000 chart showing a 0.1 Hz square wave on the GSR channel in AUTO mode.

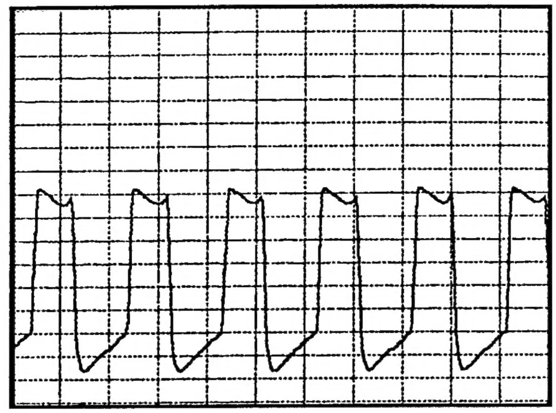

Figure 15. LX2000 chart showing a 0.1 Hz square wave on the GSR channel in MANUAL mode.

Discussion

The Lafayette LX2000 and the Axciton instruments displayed nearly identical changes in their output waveforms when switched between the AUTO and MANUAL modes of operation. However, the Axciton instrument demonstrated a pronounced positive baseline (tonic) shift in the MANUAL mode. The manufacturer is apparently aware of this situation, and customers have been advised to use the instrument only in the AUTO mode. The shift was not seen on the other two instruments. The Stoelting instrument output resembled the other two instruments in the MANUAL mode. The minor signal distortion on the triangle and square waves observed in the MANUAL mode can be attributed to the effects of rejection of high frequencies by the built-in low pass filters in the instruments.

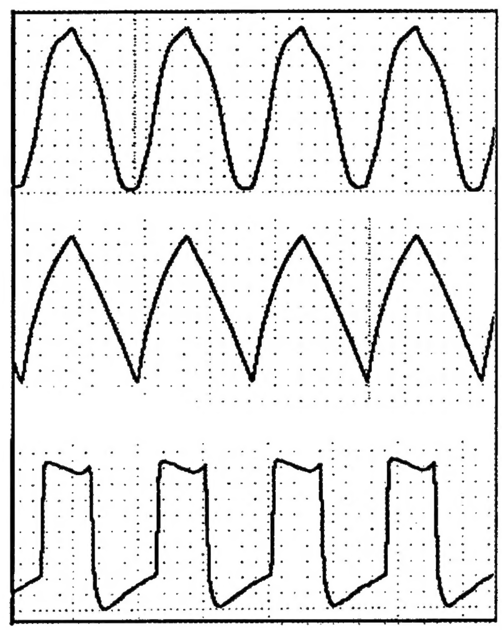

Figure 16. Stoelting CPS charts depicting 0.1 Hz sine, triangle, and square waves on the GSR channel output.

When the AUTO mode was selected on the LX2000 and the Axciton, the output signal deviation from the input signal was most apparent when the input was either a triangle or square wave, and appeared to be differentiated. This may be due to AC coupling on the input to reduce the amplifier response to DC baseline, or tonic skin resistance changes. The problem was less apparent when the input signal was a sine wave. This characteristic distortion could conceivably be considered non-problematic in the field because the GSR rise and fall times are more closely represented by the rise and fall times of the sine wave rather than by the times associated with the triangle and square waves. However, the *degree* of the observable

differences among the fast rise time signal responses, with emphasis on the triangle, indicates a disparity among instruments which is related to gross differences in the internal filtering of the physiological signal being measured (see Figures 6, 12, and 16). Filter characteristics were found to differ considerably among manufacturers, and also between different models from the same manufacturer. Additionally, amplifier gain parameters and analog to digital conversion (ADC) rates vary considerably among manufacturer's products.

Finally, there appear to be no established standards for physiological measurements within the polygraph instrument manufacturing industry, as is evident from the instrument specifications supplied by the manufacturers (Table 1). The filter characteristics for the LX2000 and LX3000 are markedly different, as are the differences among instruments from the three manufacturers. It may be prudent for the manufacturers to collectively select and agree upon channel specifications for each component and provide amplifier outputs which are accurate representations of the physiology being measured. Basic standardization may become increasingly more important as computerization is used to take advantage of scoring algorithms for automated decision-making. Currently, scoring algorithms are not portable among the different instruments, nor are the basic algorithms available for analysis by physiologists and computer scientists working in the PDD discipline. Until there is some standardization, there is no way that the most efficacious algorithms can be easily implemented in the native code for each instrument so that there will be confidence in inter-instrument scoring reliability.

Table 1

Amplifier Characteristics of Various Polygraph Instruments

Mfr.	Hi-pass filter (-3 dB)	Lo-pass filter (-3 dB)	Filter rolloff dB/octave	Electrode current uAmps*	Electrode voltage	Amplifier gain	Amplifier slew rate	AD sample rate
GSR channel								
LX3000	0 Hz	1 Hz	6	5.784	2.975 V	1 - 11	28V/mSec	120 Hz
LX2000	0 Hz	97 Hz	12	9.018	4.55 V	5 - 44	.01V/uSec	1000 Hz
Axciton	.08 Hz	5 Hz	20	2	1.0 V	5 - 40	---	30 Hz
Stoelting	---	6 Hz	18	---	---	1639	---	48 Hz
Cardio channel								
LX3000	0 Hz	48 Hz	6			356	28V/mSec	120 Hz
LX2000	0 Hz	111 Hz	12			802	.05V/uSec	1000 Hz
Axciton	0 Hz	60 Hz	20			10 - 600	---	120 Hz
Stoelting	---	30 Hz	10			174	---	48 Hz
Respiratory (pneumo) channel								
LX3000	0 Hz	16 Hz	6			196	28V/mSec	120 Hz
LX2000	0 Hz	111 Hz	12			402	.05V/uSec	1000 Hz
Axciton	0 Hz	15 Hz	20			10 - 500	---	30 Hz
Stoelting	---	15 Hz	10			60	---	48 Hz

Note. *Lafayette and Axciton assume 500K nominal skin resistance in their GSR electrode current data.